

## **TURBINE BLADE TIP WITH OPTIMIZED ABRASIVE**

### **FIELD OF THE INVENTION**

5 This invention is directed generally to coatings for turbine blades, and more particularly to turbine blade tip coatings for tip clearance control.

### **BACKGROUND OF THE INVENTION**

10 Typically, gas turbine engines are formed from a combustor positioned upstream from a turbine blade assembly. The turbine blade assembly is formed from a plurality of turbine blade stages coupled to discs that are capable of rotating about a longitudinal axis. Each turbine blade stage is formed from a plurality of blades extending radially about the circumference of the disc. Each stage is spaced apart from each other a sufficient distance to allow turbine vanes to be positioned between each stage. The 15 turbine vanes are typically coupled to the shroud and remain stationary during operation of the turbine engine.

20 The tips of the turbine blades are located in close proximity to an inner surface defined by ring segments. There typically exists a gap between each of the blade tips and the ring segments so that the blades may rotate without striking the segments. During operation, high temperature and high pressure gases pass the turbine blades and cause the blades and discs to rotate. These gases also heat the shroud and blades and discs to which they are attached causing each to thermally expand. After 25 the turbine engine has been operating for a period of time, the components reach a operating condition at which maximum thermal expansion occurs. In this state, it is desirable that the gap between the blade tips and the engineering segments be as small as possible to limit leakage of hot gases past the blade tips.

One technique for controlling the blade tip clearance relative to the ring segments is to utilize an abradable coating, such as a porous thermal barrier coating (TBC), on the hot gas path surface of the ring segments. This coating may be abraded by the blade tips and for this purpose the blade tips may be coated with an abrasive material

5 that engages and cuts the TBC.

For example, the Row 1 and 2 ring segments of a turbine can have a thick, porous coating, such as 8 wt. % yttria-stabilized zirconia (8YSZ) ceramic or another ceramic material, that is designed to insulate the metal and to be rubbed away by the

10 blade tips, thereby establishing blade tip clearance. This coating can be prepared by thermally spraying a combination of the ceramic powder and a fugitive material such as a polymer to produce an abradable coating on the ring segment. The corresponding Row 1 and 2 turbine blade tips can be coated with a thin layer of cubic boron nitride (cBN) that allows the blade tips to engrave the ceramic. However, operational

15 experience has shown that the abradability of this blade tip clearance control system is insufficient.

One of the possible causes for this reduced abradability is the degradation of the cBN after exposure to the > 1000°C gas temperatures to which the blade tips are

20 exposed during operation of the turbine engine. While cBN abrasives exhibit excellent cutting ability when new, thermal decomposition of the cBN particles in an elevated temperature oxidizing environment produces effectively bare blade tips, which have been shown to have very limited cutting ability and which result in unacceptable blade tip wear.

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## SUMMARY OF THE INVENTION

It is an object of the invention to provide improved blade tip clearance control, and thus increased engine efficiency, by maintaining abrasion characteristics of an

abrasive tipped blade while providing resistance to thermal degradation of the abrasive. It is another object of the invention to provide an abrasive blade tip coating that increases the effective lifetime of abrasive blades in the engine. It is a further object of the invention to reduced the risk of blade tip wear due to rubbing.

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These and other objects of the invention are achieved by aspects of the invention directed to a turbine blade tip coating in which a portion of cubic boron nitride (cBN) is substituted with silicon nitride ( $Si_3N_4$ ). A turbine blade with abrasive tip coating can include an elongated turbine blade having a tip at one end. The tip can have an 10 abrasive coating including a mixture of cBN and  $Si_3N_4$ . Preferably, the abrasive coating includes a roughly 50:50 mixture of cBN and  $Si_3N_4$ .

15 The abrasives can be placed, such as by electroplating or other deposition technique, on the blade tip and be included in a super alloy matrix that is preferably nickel and/or cobalt-based. The super alloy can be CoNiCrAlY and may have other added elements for enhanced oxidation life.

According to aspects of the invention, a turbine blade and ring segment 20 assembly can be provided that includes a turbine ring segment having an abradable coating on an inner surface thereof and a turbine blade having a tip at one end. The blade tip can have an abrasive coating that engages and abrades an abradable coating of the turbine ring segment. As noted above, the abrasive coating of said blade tip includes a mixture of cBN and  $Si_3N_4$ , that is preferably a roughly 50:50 mixture of cBN and  $Si_3N_4$ . The abradable material of the ring segment can be a thermal barrier coating 25 that is porous and ceramic based. The thermal barrier coating can include yttria-stabilized zirconia (8YSZ is a commonly used TBC material) or another suitable ceramic material.

These and other embodiments are described in more detail below.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The accompanying drawings, which are incorporated in and form a part of the specification, illustrate embodiments of the presently disclosed invention and, together with the description, disclose the principles of the invention.

FIG. 1 is a schematic sectional view of a turbine blade tip and ring segment assembly with respective abrasive and abradable coatings according to aspects of the invention.

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**DETAILED DESCRIPTION OF THE INVENTION**

The invention is directed to an improved blade tip treatment to provide improved blade tip clearance control in the turbine section of an industrial gas turbine (IGT).

15 While the embodiments disclosed are directed to abrasive clearance control between turbine blade tips and surrounding turbine ring segments, the coatings according to aspects of the invention can have application to other turbine components.

Referring to FIG. 1, a turbine blade 10 provides at its radially outer end a blade tip 12. The blade tip 12 is positioned relative to the radially inner surface 14 of a turbine ring segment 16 with as small a clearance as possible to minimize the leakage of the turbine hot gas flow past the blade tip 12, with the associated loss in turbine efficiency.

20 In an abrasion based tip clearance control system, the position of the blade tip 12 relative to the ring segment 16 is designed to allow abrasive contact between the blade tip 12 and the radially inner surface 14 of the ring segment 16. The blade tip 12 can be provided with an abrasive coating 18 while the ring segment 16 can provide an abradable coating 20 so that during rotational contact, the abrasive coating 18 of the

blade tip 12 engravés the abradable coating 20 of the ring segment 16 and establishes an essentially zero blade tip clearance.

According to aspects of the invention, the turbine blade tip 12 is coated with a mixture of a hard abrasive possessing limited oxidation resistance and a softer, more oxidation-resistant abrasive. The blade 10 can have a metallic coating 18 on its tip 12, containing the hard abrasive particles 22, 24. The initial engraving can be achieved by the inclusion in the blade tip abrasive coating 18 of cubic boron nitride (cBN) 22, which exhibits superior cutting properties. The abradable coating 20 of the ring segment 16 is preferably a thermal barrier coating. The thermal barrier coating is preferably porous, and preferably includes yttria-stabilized zirconia (YSZ), although the disclosed invention may be used with any porous, abradable ceramic material. The abrasive properties of cBN have been found particularly suitable for engraving a porous thermal barrier coating including 8 wt. % yttria stabilized zirconia (8YSZ).

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Because cBN degrades in the high temperature environment of a turbine engine, the cutting ability of a blade tip coated with cBN diminishes over engine operation time and bare metal tip wear occurs. According to aspects of the invention, a portion of the cBN in the coating matrix can be substituted with silicon nitride ( $Si_3N_4$ ) 22. While  $Si_3N_4$  does not provide the equivalent cutting ability of cBN, due to  $Si_3N_4$ 's lower hardness,  $Si_3N_4$  demonstrates greater resistance to thermal degradation in the high temperature, oxidizing environment of the turbine engine.  $Si_3N_4$  also exhibits excellent resistance to reaction with cobalt and nickel commonly found in the super alloy metal matrix used to bond the cBN to the blade tip.

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By producing a blade tip coating comprised of varying amounts of cBN and  $Si_3N_4$ , the excellent initial cutting ability of cBN can be exploited, while at the same time retaining the  $Si_3N_4$  abrasive for longer times to provide improved cutting ability versus the effectively bare blade tip that would otherwise be left after cBN degradation. The

cBN and  $\text{Si}_3\text{N}_4$  abrasive mixture can be included in a super alloy metal matrix, which is preferably nickel and/or cobalt based, such as CoNiCrAlY.

Preferably, the mixed abrasive tip coating includes a 50:50 mixture of cBN and

5  $\text{Si}_3\text{N}_4$ . Relative amounts of these abrasives can be varied to suit the specific engine application, and the relative percentages of cBN and  $\text{Si}_3\text{N}_4$  should be chosen based on the anticipated amount of porous TBC to be removed during initial cutting and on the predicted amount of TBC to be removed after such time as the cBN has been rendered ineffective.

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In testing of the preferred coatings, approximately equal amounts of cBN and  $\text{Si}_3\text{N}_4$  were applied to subscale turbine blade tips via electroplating and were tested against a porous 8YSZ coating to measure cutting ability. These tips were also thermally exposed to a simulated turbine gas path environment for various times to 15 establish their resistance to thermal degradation. Surprisingly, the initial (non-thermally degraded) cutting capability of the mixed abrasive tip was shown to be comparable to a tip with 100% cBN, demonstrating that the blade's initial cutting capability is not substantially sacrificed by replacing some of the cBN abrasive particles with  $\text{Si}_3\text{N}_4$ . An identical blade was then exposed to a 1000°C oxidizing environment similar to that 20 experienced by an actual turbine engine blade, for a period of 200 hours. This blade was tested against a sintered (thermally exposed) porous 8YSZ coating and its cutting ability, while much reduced versus the fresh blade, was superior to that of a similarly exposed blade with tip comprised solely of cBN.

25 The foregoing is provided for purposes of illustrating, explaining, and describing embodiments of this invention. Modifications and adaptations to these embodiments will be apparent to those skilled in the art and may be made without departing from the scope or spirit of this invention, as defined in the following claims.